Effect of Sequential Treatment of Warm Water Dip and Low-dose Gamma Irradiation on the Quality of Fresh-cut Green Onions

HYUN JUNG KIM, HAO FENG, STOYAN A. TOSHKOV, AND XUETONG FAN

ABSTRACT: The effect of warm water dip in combination with irradiation on quality of fresh-cut green onions was studied. Fresh-cut green onions were treated with and without warm water (50 °C for 20 s) and packaged prior to irradiation at 0, 0.5, 1.0, and 1.5 kGy, then stored at 4 °C for 14 d. Color, texture, decay percentage, electrolyte leakage, sensory qualities, and total aerobic count (TAC) were measured at 1, 4, 8, and 14 d of storage. The warm water treatment reduced the TAC by 0.9 log initially but the beneficial effect disappeared during storage. With the test conditions used in this study, the warm water treatment did not provide added benefits for quality improvements. Irradiation at all tested doses reduced TAC and the development of decay and off-odor, improved visual quality, and preserved green color.

Keywords: irradiation, warm water wash, sequential treatment, green onions, fresh-cut

Introduction

Green onion (*Allium fistulosum* L.) is a popular seasoning vegetable in Asian and Mexican cuisines. The fresh leaves of green onions are rich in vitamins A and C and also contain a sulfide of the radical allyl, a bioactive compound with antimicrobial effects (Augusti 1990). However, green onion is highly perishable, having a limited storage life of only 7 to 10 d at 10 °C. In addition, the safety of green onions has raised concerns due to the recent food-borne illness outbreaks associated with the consumption of green onions contaminated with viruses and human pathogens. The 2003 hepatitis A outbreak in Monaca, Pa., U.S.A., that killed 3 people and sickened nearly 600 others has been suggested to be related to raw or undercooked green onions served in restaurants (CDC 2003). Green onions contaminated with *Shigella* were identified as the source of at least one other outbreak (Cook and others 1995). Surveys conducted by the Food and Drug Administration also showed a high rate of *Shigella* in imported green onions (FDA 1999). In recent years, the fast growth of the fresh-cut produce industry has stimulated the production and consumption of fresh-cut green onions. Fresh-cut produce is more easily contaminated by spoilage microorganisms and food-borne pathogens through damaged and decayed leaf tissues compared with whole produces (Wang and others 2004). An effective food safety intervention for fresh-cut green onions is, therefore, indispensable.

A common practice in fresh-cut produce production is to use chlorinated water wash to inactivate spoilage-causing microorganisms and eliminate food-borne pathogens. In recent years, new alternatives have been studied to find more effective and environmentally friendly techniques to secure fresh produce safety. Immersion of fruits and vegetables in water at mild temperatures has been used to control insect infestation and surface microorganisms (Lurie 1998). Apples (Lurie and Klein 1990) and broccoli (Tian and others 1997) treated with warm water at 38 and 47 °C, respectively, had an improved storage performance. Delaquis and others (1999) demonstrated that microbial population was decreased up to 3 logs in shredded iceberg lettuce washed with chlorinated water at 47 °C compared with that washed at 5 °C, which recorded a 1-log reduction. Furthermore, warm water treatment inactivated phenylalanine ammonia lyase in iceberg lettuce (Loaiza-Velarde and others 1997), a key enzyme for the synthesis of phenolic compounds.

Irradiation has a strong bactericidal effect that can be used to eliminate microorganisms that cause food spoilage and food-borne illnesses, and to extend shelf life. Low-dose irradiation has been studied for inactivating pathogenic microorganisms, including *Listeria monocytogenes* and *Escherichia coli* in diced celery by Prakash and others (2000) and *Salmonella* and *Escherichia coli* in alfalfa sprouts by Thayer and others (2003). Prakash and others (2000) reported that a 1-kGy treatment eliminated all *L. monocytogenes* and *E. coli* inoculated on diced celery while extending shelf life and maintaining preferred sensory quality. Rajkowski and Thayer (2001) used gamma irradiation on fresh alfalfa sprouts and found that a dosage of 2.0 kGy was effective to decrease total aerobic count from 10^{5-8} to 10^{3-5} colony-forming units (CFU)/g and total coliform count from 10^{5-8} to 10^{3-0} CFU/g while product quality was maintained. Fan and others (2003a) used ionizing radiation at doses up to 3 kGy to treat fresh cilantro and reported that irradiation at 2 kGy retained its sensorial quality and shelf life with a reduction of total aerobic plate count. Nevertheless, several studies have shown undesirable textural changes in fresh produce induced by irradiation (Kertesz and others 1964; Massy and Bourke 1967).

It is generally agreed that irradiation doses above 1 kGy would damage produce and hence doses of over 1 kGy are seldom used for produce irradiation (McDonald and Miller 1995). With such low doses, however, some food-borne pathogens and most viruses cannot be effectively eliminated. For example, the D values (doses that inactivate a specific microorganism by 90%) for hepatitis A are 2.72 ± 0.05 and 2.97 ± 0.18 kGy in lettuce and strawberries, respectively (Bidawid and others 2000). To meet this challenge, combination

MS 20040687 Submitted 10/14/04, Revised 12/6/04, Accepted 12/13/04. *Author Kim, Feng, and Toshkov are with Dept. of Food Science and Human Nutrition, Univ. of Illinois at Urbana-Champaign, Urbana, IL 61801. Author Fan is with Eastern Regional Research Center, USDA, Wyndmoor, Pa. Direct inquiries to author Feng (E-mail: haofeng@uiuc.edu).*

of irradiation with other treatment(s) has been explored in recent years. Gagnon and others (1993) and Lacroix and others (1991, 1993) used ionizing radiation in combination with warm water dip to extend the shelf life of fresh mangoes. Fan and others (2003b) tested the combination of warm water wash (47 °C) with irradiation to improve fresh-cut iceberg lettuce quality in storage. They found that the combined treatment was effective to maintain overall quality with less tissue browning.

We, therefore, hypothesized that a sequential treatment of fresh-cut green onions with warm water immersion, followed by ionizing irradiation would provide adequate microbial reduction while maintaining product quality. The objective of this study was to examine the efficacy of sequential treatment of warm water dip and irradiation on microbial inactivation and quality retention on fresh-cut green onions.

Materials and Methods

Sample preparation and treatment

Fresh green onions (*Allium fistulosum* L.) were purchased from a local produce provider in Urbana, Ill., and held at 0 °C until use. Green onions were trimmed and all roots, compressed stems, and white leaf sheath were removed. After washing the green onion leaves with tap water at less than 18 °C, the green leaf blades were cut with a stainless steel knife into approximately 1 cm length, which is a form of fresh-cut green onions available for food service. The green onion rings were divided into 2 lots for irradiation alone treatment (IR) and for warm water treatment followed by irradiation (WW-IR). Right after the tap water washing, green onion rings were taken as the controls. The warm water dip was conducted by submerging green onion samples, which are placed into a screen basket, in a water bath at 50 °C for 20 s (1:15 green onion to water ratio). To determine the optimum water temperature and treatment time, a preliminary experiment was conducted in which green onions were subjected to warm water dip at 45, 50, and 55 °C for 10, 15, and 20 s. The results showed that treatment at 50 °C for 20 s yielded relatively high natural flora reduction while maintaining product quality, and therefore was chosen for use in the subsequent experiments. During the warm water treatment, the water temperature was maintained within ±1 °C of the target value, and the screen basket was shaken to provide a uniform heat transfer. The samples were then dried with a kitchen salad spinner (World Kitchen Inc., Elmira, N.Y., U.S.A.). Dewatered samples (approximately 110 g) were packaged in perforated Ziploc® storage bags (S.C. Johnson & Sons Inc., Racine, Wis., U.S.A.). There were 4 bags of fresh-cut green onions for each treatment. All bags (32 bags/run) of the green onions were placed in a refrigerator and then gamma irradiated at doses of 0 (control), 0.5, 1.0, and 1.5 kGy within 1 h. Irradiated samples were stored in a refrigerator maintained at 4 °C for up to 14 d and separate bags were used for each storage day (1, 4, 8, and 14 d).

Irradiation and dosimetry

The irradiation was performed with a Gammacell 220 Excell Cobalt irradiator (MDS Nordion 447, Ontario, Canada, K2K 1×8) located in the Nuclear Engineering Lab at Univ. of Illinois. It was loaded in October of 2002 with 24000 Curie of Cobalt-60. The irradiation chamber was a cylinder with dimensions of 203 mm (8 inches) height and 152 mm (6 inches) in diameter. Precise dose distribution in the irradiation chamber was measured through the use of Gafchromic MD-55 (ISP Technologies Inc., Wayne, N.J., U.S.A.) and Radiachromic FWT-60 film dosimeters (Far West Technology, Inc., Goleta, Calif., U.S.A.), which were calibrated in the Natl. Inst. of Standards and Technology. In order for green onion samples to receive uniform radiation, each sample bag was placed at the location in the chamber where a nearly uniform field distribution was found with the Gafchromic MD-55 and Radiachromic FWT-60 films. A thin paper cup placed on a polyethylene foam base was used to hold and position the sample bags. The size of the 110 g green onion bags was small enough to allow all green onion leaves to be placed within the zone where the field distribution was nearly uniform. The sample temperature during irradiation was monitored and maintained at 23 °C by air circulation. The dose rate for the experiments was 0.25 kGy/min.

Color analysis

Color values, the CIE (Commission Intl. de l'Eclairage) L^*, a^*, b^* of green onions, were measured on days 1, 4, 8, and 14 using a Hunter Labscan XE colorimeter (Hunter Associates Laboratory, Reston, Va., U.S.A.) calibrated with the standard white and black tiles. The illuminant/viewing geometry was D65/10°. Seventeen grams green onion rings were placed into an empty Petri dish, and the L^*, a^*, and b^* values were recorded. Color readings reported are the mean of 4 determinations taken from each bag. Chroma (C) and hue angle (H) were calculated as $C = (a^{*2} + b^{*2})^{0.5}$ and H = arctangent (a^*/b^*) (McGuire 1992).

Firmness

Share force of green onion leaves was determined using a Texture Analyzer (Model TA-XT2i, Texture Technology Corp., Scarsdale, N.Y., U.S.A.) with a mini-Kramer Shear Press with 5 blades. A 5-g sample was placed into the square metal container and then the 5-blade plunger was forced through the green onion rings at a speed of 2 mm/s. The probe stopped at 10 mm from the bottom of the container. The maximum force (g) was recorded automatically by a Texture Expert software program (version 1.22, Texture Technology Corp, Scarsdale, N.Y., U.S.A.). Measurements of share force were conducted using 4 samples for each treatment.

Electrolyte leakage

The electrolyte leakage of green onions was measured with an AB30 conductivity meter (Fisher Scientific, Hanover, Ill., U.S.A.). Five grams of green onion rings was put into a 125-mL Erlenmeyer flask containing 50 mL deionized water and incubated for 60 min at room temperature (23 °C). Electrical conductivity of the water was measured (initial reading) and then final conductivity was read after autoclaving samples for 35 min in an autoclave (Model 8000-DE, Napco, Winchester, Va., U.S.A.). Electrolyte leakage was expressed as a percentage of initial to final readings, and there were 4 measurements for each treatment.

Decay percentage

Decay of fresh-cut green onions during storage was determined by the weight ratio of decayed leaves to total weight of the leaves in a bag. A piece of leaf was counted as decayed if it exhibited a significant discoloration, was excessively watery or dry compared with the bulk sample, or when a part or the entire ring became decomposed or rotted. Decay percentage was measured before all other tests were conducted.

Sensory evaluation

All samples were visually evaluated by 5 to 6 judges for overall visual quality, greenness, aroma, and off-odor of fresh-cut green onions. Panelists had experiences with sensory panels but were not trained. The samples were randomly coded with three-digit numbers to mask the treatment identity. For overall visual quality, the

Table 1—Effect of warm water dip and irradiation on *L, chroma[a], and hue angle[b] of fresh-cut green onions during storage at 4 °C**

		IR Dose (kGy)				WW-IR Dose (kGy)			
	Day	0	0.5	1.0	1.5	0	0.5	1.0	1.5
*L**	1	30.6 ± 2.0	27.0 ± 3.8	26.9 ± 1.4	29.2 ± 5.6	27.9 ± 1.5	29.8 ± 4.4	26.5 ± 2.1	30.2 ± 3.2
	14	32.7 ± 2.6	31.2 ± 1.1	33.7 ± 0.6	29.6 ± 6.6	30.1 ± 1.1	30.4 ± 3.7	33.7 ± 6.1	30.5 ± 0.5
C	1	22.4 ± 5.1	22.3 ± 1.9	22.8 ± 4.7	22.3 ± 2.7	24.6 ± 2.1	24.4 ± 1.4	24.7 ± 0.6	24.8 ± 1.5
	14	24.9 ± 3.7	23.3 ± 3.0	26.8 ± 2.6	23.9 ± 1.1	25.9 ± 2.9	23.3 ± 0.9	25.8 ± 3.0	23.2 ± 4.4
H	1	115.2±3.8	114.6±1.0	114.2±3.3	114.2±0.6	112.4±2.3	113.5±1.7	113.2±0.3	113.0±1.6
	14	111.7±3.1	112.6±1.8	110.1±1.9	110.4±1.5	110.1±2.6	111.0±1.5	109.5±1.8	109.0±0.4

Samples treated with and without warm water were irradiated at 0, 0.5, 1.0, and 1.5 kGy and then stored at 4 °C. Color was measured at 1, 4, 8, and 14 d of storage. All data represent means of 12 measurements (Means ± S.D).
[a]Chroma (C) was calculated as $C = (a^{*2}+b^{*2})^{1/2}$.
[b]Hue angle (H) was calculated as H = arctangent (b*/a*) (0 = red-purple, 90 = yellow, 180 = bluish-green, 270 = blue).

appearance of green onions was based on a 9-point scoring method (9 = excellent, 7 = good, 5 = fair, 3 = poor, and 1 = unusable). Green color was evaluated using a 5-point scoring system (5 = dark green, 3 = green, and 1 = yellow). Aroma and off-odor of green onion were rated on a 5 to 1 scale (5 = maximum, 1 = none; 5 = severe, and 1 = none).

Microbial analysis

Total aerobic CFU were determined by a standard spread-plate method at 0, 1, 4, 8, and 14 d of storage. Duplicate samples of green onions were tested for each treatment. Ten grams of green onion samples was mixed with 90 mL sterile peptone water (0.1% peptone and 0.85% NaCl) in a stomacher bag and agitated for 30 s after closing the bag (Fan and others 2003c). A 1-mL aliquot was serially diluted into 9 mL sterile peptone water and then 0.1 mL was placed on tryptic soy agar (Difco, Detroit, Mich., U.S.A.). Samples were spread on 3 plates per each dilution. Plates were incubated at 37 °C for 24 h. Plates with CFU between 20 and 200 were counted, and CFU reported are the average of 6 plates.

Statistical analysis

The experiment was done in triplicates. For each replicate, 3 bags of samples from each treatment were tested, and green onion leaves in each bag were divided into 2 sub-samples for measurement. Data were analyzed by one-way analysis of variance using the Statistical Analysis System (SAS Inst., Raleigh, N.C., U.S.A.). When there was a difference among treatments at $\alpha = 0.05$, the Fisher's least significant difference test was performed to distinguish differences among means.

Results and Discussion

Color

*L**, chroma values, and hue angles of fresh-cut green onions after 1 and 14 d storage are shown in Table 1 (data from 4 and 8 d not shown). Statistic analyses were performed to distinguish the effect of irradiation dose on color changes for irradiation (IR) and warm water followed by irradiation (WW-IR) samples. There was no significant difference among samples irradiated with different doses for both treatments at $P > 0.05$. However, small changes in sample color over storage time were recorded as evidenced by an increase in *L** and chroma values, and a decrease in hue angles, except the chroma values at day 14 for WW-IR treatment at 0.5 and 1.5 kGy.

Compared with the control, irradiation treatment at 3 doses did not significantly change chroma values, which was different from the observations of Fan and others (2003a) who found that irradiated fresh-cut green onions at 1, 2, and 3 kGy generally had increased chroma values during storage. Hue values of green onions decreased with storage time for both treatments, indicating that the color of green onions shifted toward the yellow end of the spectrum during storage, which is in agreement with our visual observations (Table 2). Losing green pigmentation accompanied by the predominance of yellow pigments is a natural process in the senescence of many fruits and vegetables, and such changes can be accelerated by ethylene. A stress to plant tissues increases ethylene production and respiration rate (Garcia and Barrett 2002), and thereby increases yellow pigments. Irradiation and warm water dip as added stresses to plant tissues should have accelerated the color changes in fresh-cut green onions toward more yellowish. However, hue values obtained in this study at different doses did not show a significant difference (Table 1). Visual observations of greenness given in Table 2 showed an even more green color for irradiated samples than the control after 14 d of storage. Overall, with the irradiation doses (0.5, 1.0, and 1.5 kGy) and warm water dip condition (50 °C for 20 s) used in this study, the color changes are either insignificant or very minor.

Decay percentage

Decay percentages in fresh-cut green onions treated with IR and WW-IR generally increased over storage time at 4 °C (Figure 1), with a little decay development in the 1st 8 d of storage. There were no significant differences in decay percentage among the samples treated with different doses and treated with 2 methods at 1, 4, and 8 d of storage. At day 14, however, the decay percentage in nonirradiated green onions (0 kGy), regardless of treatment, was significantly higher than that in the irradiated samples. For the nonirradiated samples (0 kGy), warm water dip seemed to have a slightly lower decay rate (22.1%) as compared with those without warm water treatment (25.5%). It is noted that irradiated samples did not show a significant difference in decay percentages among irradiation doses (0.5 to 1.5 kGy) and between the 2 treatments even after a 14-d storage. Fan and others (2003a) investigated the effect of irradiation on quality of fresh cilantro leaves and found that samples irradiated at 1 kGy had a decay percentage similar to that of nonirradiated cilantro while at a dose of 3 kGy, the decay of irradiated samples was much higher than the nonirradiated samples. The different decay behavior of green onions and cilantro may be caused by a difference in sensitivity to irradiation between the 2 plants, as well as by the warm water dip used in this study. In a study on the quality of fresh broccoli dipped in warm water reported by Forney (1995), researchers noticed that warm water immersion effectively controlled decay in a 50 °C (20 to 40 s dipping) treatment whereas when the dipping temperature was increased to 60 °C, an increase in decay was observed. In a preliminary test, water dipping

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Table 2—Effect of warm water dip and irradiation on sensory characteristics of fresh-cut green onions during storage at 4 °C

		IR Dose (kGy)				WW-IR Dose (kGy)			
	Day	0	0.5	1.0	1.5	0	0.5	1.0	1.5
Overall visual quality[a]	1	8.4	7.8	8.2	8.1	8.4	7.7	7.8	8.3
	4	6.6	5.6	6.2	6.0	6.6	6.6	6.2	6.6
	8	5.4	5.4	5.6	5.9	5.3	5.2	5.4	5.2
	14	2.4a	3.4b	4.0b	4.1b	2.6A	3.4B	3.0B	3.4B
Green color[b]	1	4.7	4.6	4.6	4.6	4.7	4.5	4.5	4.5
	4	3.8	3.8	3.7	3.9	3.8	3.7	4.0	3.7
	8	3.5	3.7	3.7	4.0	3.7	3.8	3.6	3.9
	14	2.0a	2.8b	3.0b	2.9b	2.2A	2.8B	2.8B	2.9B
Aroma[c]	1	3.5	3.3	3.4	3.5	3.3	3.2	3.3	3.3
	4	2.2	2.3	2.4	2.3	2.1	2.0	2.4	2.4
	8	2.2	2.4	2.3	2.3	2.2	2.2	2.4	2.4
	14	2.1	2.0	2.1	2.2	2.0	1.8	1.9	2.3
Off-odor[d]	1	1.1	1.0	1.0	1.0	1.0	1.1	1.0	1.0
	4	2.3	1.4	1.4	1.4	1.9	1.3	1.3	1.3
	8	2.5a	1.2b	1.1b	1.2b	2.2A	1.2B	1.3B	1.3B
	14	3.6a	1.5b	1.5b	1.4b	3.4A	1.5B	1.6B	1.4B

Samples treated with and without warm water were irradiated at 0, 0.5, 1.0, and 1.5 kGy and then stored at 4 °C. Sensory attributes were evaluated at 1, 4, 8, and 14 d of storage. All data represent means of 30 to 36 observations. Different letters within a row are significantly different at $P < 0.05$.
[a]Scoring system of overall visual quality: 9 = excellent, 7 = good, 5 = fair, 3 = poor, 1 = unusable.
[b]Scoring system of green color: 5 = dark green, 3 = green, 1 = yellow.
[c]Scoring system of aroma: 5 = maximum, 3 = moderate, 1 = none.
[d]Scoring system of off-odor: 5 = severe (poor), 3 = moderate, 1 = none.

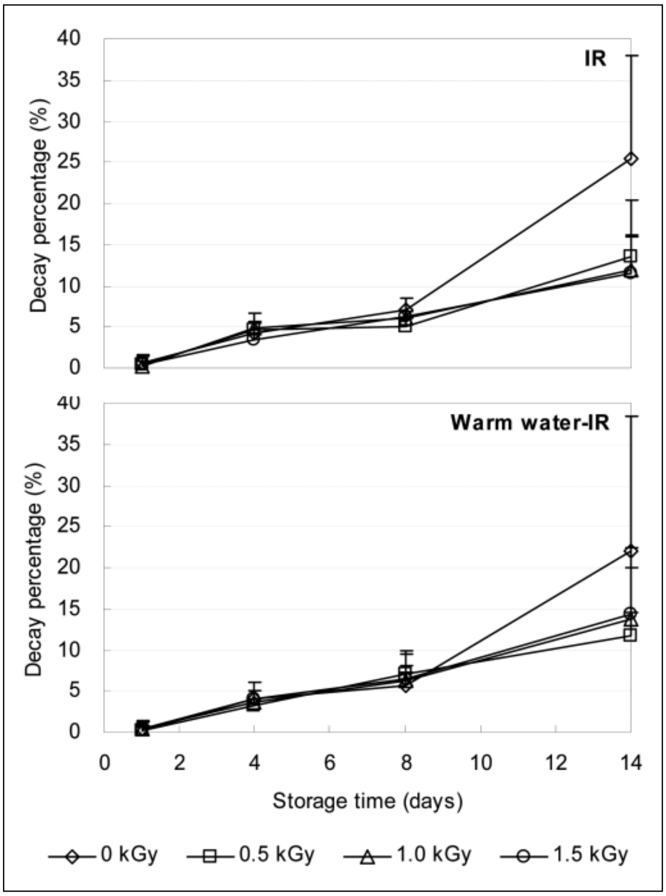

Figure 1—Effect of warm water dip and irradiation on decay percentage of fresh-cut green onions during storage. Samples treated with and without warm water were irradiated at 0, 0.5, 1.0, and 1.5 kGy and then stored at 4 °C. Decay percentage was measured at 1, 4, 8, and 14 d of storage. All data represent means of 3 replicates. Error bars indicate standard deviation of the means.

at 60 °C resulted in the highest green onions decay among 3 temperatures (45, 50, and 60 °C). To reduce quality degradation caused by elevated temperature while maintaining relatively high microbial reduction, 50 °C was selected as the water dip temperature in subsequent tests. There might be an optimal washing temperature at which the decay can be further depressed in a sequential treatment of warm water dip followed by irradiation.

Electrolyte leakage (%)

Electrolyte leakage (EL) values of fresh-cut green onions treated with IR and WW-IR are shown in Figure 2. The EL of samples from each treatment at different doses gradually increased over time. No significant difference in EL was noted between the 2 treatments except on day 14. This may indicate that washing with warm water at 50 °C for 20 s did not introduce additional damage to cell membranes. On day 14, EL of nonirradiated (0 kGy) samples for both treatments was much higher than that of the irradiated samples, which is in agreement with the high decay percentage of the nonirradiated samples at day 14 as shown in Figure 1. Between 2 nonirradiated samples, green onions without warm water treatment had an EL of 41.1%, which was slightly (not significantly) higher than the 35.4% EL for samples with warm water dip. During storage, samples irradiated at doses of < 1 kGy did not show a higher EL compared with the corresponding nonirradiated samples treated under same conditions. Irradiation seemed to have depressed the EL development toward the end of the 14-d storage.

The effects of warm water wash and irradiation on produce quality have been examined by several scientists through the determination of EL. Fan and others (2003c) reported that green onions irradiated with doses up to 3 kGy exhibited a higher EL at day 1 compared with the nonirradiated, but toward the end of the 14-d storage, the nonirradiated samples had a significant increase (at least 48%) in EL compared with the irradiated counterparts. The higher EL in the nonirradiated samples was similar to our observations in the present study. Fan and others (2003b) examined the effects of warm water (47 and 50 °C) and irradiation (up to 2 kGy) combined treatments on storage quality of fresh-cut iceberg lettuce and reported significantly higher EL values for nonirradiated samples, at least double in value over those of the irradiated samples, during a 21-d storage. In their study, there seemed to be a combined contribution from both warm water wash and irradiation treatment to the relatively low EL of lettuce leaves. Irradiation and warm water, as processing stresses, can influence the physiological status of plant tissue and alter cell membrane integrity. That may result in higher leakages as reported in irradiation studies with potato tuber (Hayashi and others 1992) and tomato (El Assi and others 1997) if the doses are relatively high for the plant under study. On the other hand, irradiation can delay ripening or senescence of many fruits and vegetables (Murano 1995), while warm water treatment at a proper temperature can induce the formation of heat shock proteins, and thereby contribute to improved storage quality. These complicated biological and biochemical responses are highly product specific and need to be carefully studied to achieve better storage quality. The growth in microorganism population and decay can also contribute to EL readings.

Firmness

Firmness of fresh-cut green onions did not exhibit a consistent change in samples from both treatments during the 1st 8 d of storage (Figure 3). However, there were slight decreases in firmness of all samples after 8 d of storage, and this decrease was more pronounced for warm water treated samples than for those without warm water treatment. Compared with the nonirradiated samples in the 2 treatments, irradiated samples had lower firmness at 1 and 4 d of storage but this trend was reversed at day 14 so that at day 14, the nonirradiated had the lowest firmness values in both treatments. Firmness is an important quality factor for many horticultural products. It has been associated with cell morphology, turgor, and cell wall-middle lamella structure (Harker and others 1997). Loss of firmness may be attributed to the cell injury caused by treatments. Irradiation at high enough doses promoted softening of plant tissue caused by changes of pectic substances as well as degradation of celluloses (Faust and others 1967; Prakash and others 2000). Previous investigations showed that gamma-irradiation at greater than 0.34 kGy caused significant softening in the firmness of apple slices, which was related to an increase in the content of water-soluble pectin, not the total pectin content (Gunes and others 2001). On the other hand, heat treatment has been shown to have the potential to improve product firmness. Kim and others (1994) found that heat treatment (45 °C, for 1.75 h) of whole fruit yielded firmer products compared with non-heated fruit but there was a decrease in firmness with longer storage. Our results showed that neither irradiation nor warm water treatment had any consistent effect on the texture of fresh-cut green onions.

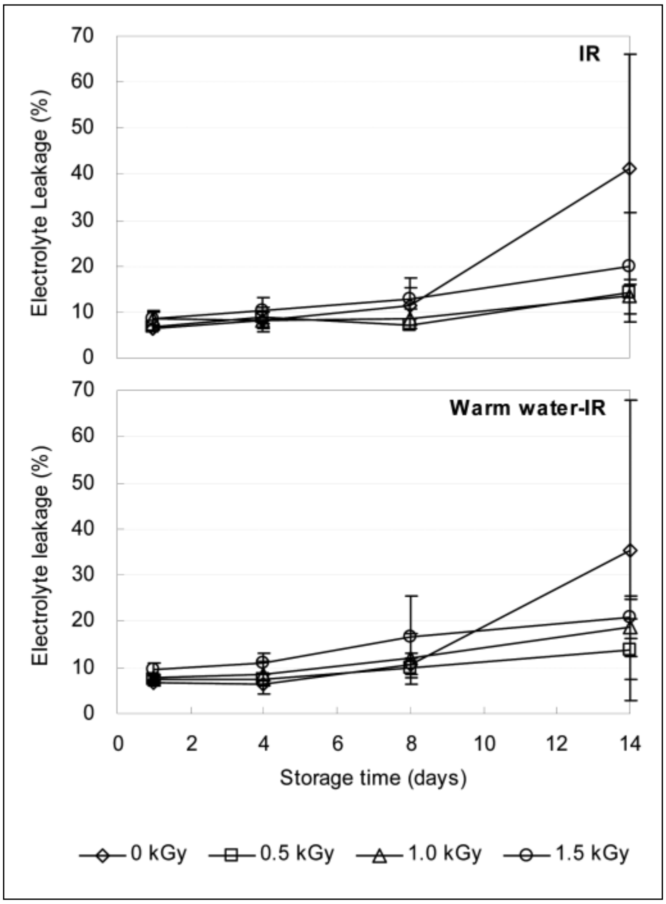

Figure 2—Effect of warm water dip and irradiation on electrolyte leakage of fresh-cut green onions during storage. Samples treated with and without warm water were irradiated at 0, 0.5, 1.0, and 1.5 kGy and then stored at 4 °C. Electrolyte leakage was measured at 1, 4, 8, and 14 d of storage. All data represent means of 6 measurements. Error bars indicate standard deviation of the means.

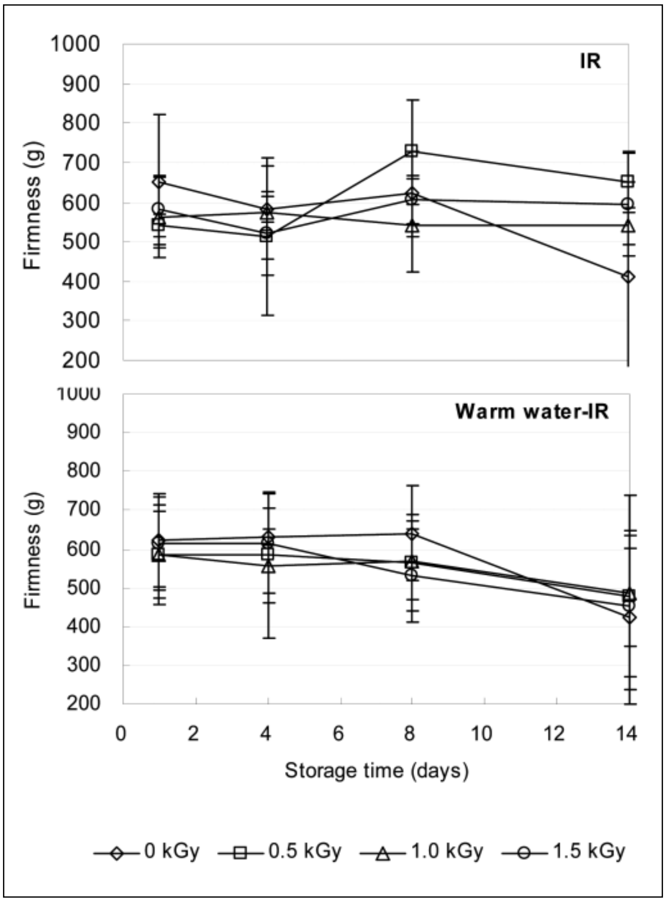

Figure 3—Effect of warm water dip and irradiation on firmness of fresh-cut green onions during storage. Samples treated with and without warm water were irradiated at 0, 0.5, 1.0, and 1.5 kGy and then stored at 4 °C. Firmness was measured at 1, 4, 8, and 14 d of storage. All data represent means of 3 replicates (4 readings/1 replicate). Error bars indicate standard deviation of the means.

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Sensory evaluation

Overall visual quality of green onions gradually deteriorated over time (Table 2). Compared with irradiated samples, nonirradiated samples had higher visual quality scores at 1 and 4 d of storage. Afterward, irradiated green onions seemed to maintain visual quality better than nonirradiated in both treatments, as indicated by higher visual quality scores. At 14 d, the quality of all samples was scored between "fair" and "poor," which means the shelf-life of fresh-cut green onions would be less than 14 d. Warm water dip had no significant effect on overall visual quality. It is worth mentioning that, at day 14, irradiation with doses of 0.5 to 1.5 kGy significantly reduced overall quality losses and the green onions irradiated at 1.5 kGy had the best quality among all the samples in both treatments. The greenness scores for all samples decreased during storage (Table 2). There was no noticeable color change until 14 d of storage. The irradiated samples had greater stability of color than the nonirradiated. Similar to the overall visual quality, nonirradiated samples treated with and without warm water had less fresh green color than irradiated ones at d 14. Typically, aroma scores decreased during the storage time even though there were no significant differences among samples at $P > 0.05$ (Table 2). Green onions had little odor after 1 d in storage. From 4 to 14 d, there was no great change of aroma in all samples. On average, green onions treated without warm water had slightly (not significantly) better aroma than those with warm water. Off-odor intensity increased in all samples overtime while aroma scores decreased (Table 2). Irradiation significantly depressed the off-odor scores during storage for both treatments at days 8 and 14.

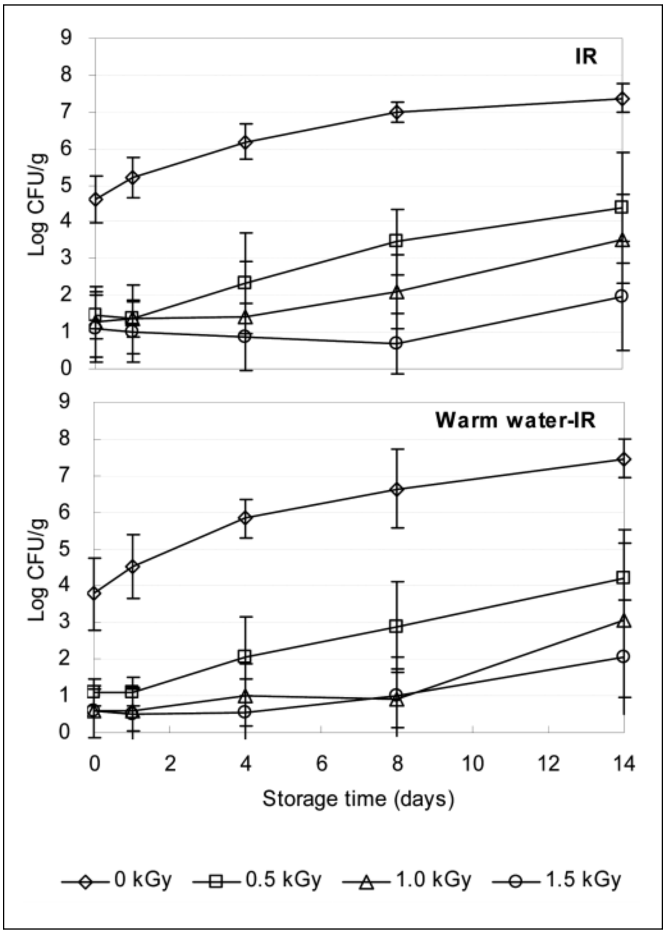

Figure 4—Effect of warm water dip and irradiation on decay percent of fresh-cut green onions during storage. Samples treated with and without warm water were irradiated at 0, 0.5, 1.0, and 1.5 kGy and then stored at 4 °C. TAC was measured at 0, 1, 4, 8, and 14 d of storage. All data represent means of 6 plates. Error bars indicate standard deviation of the means.

Microbiological analyses

The total aerobic count (TAC) of fresh-cut green onions stored at 4 °C increased over storage time (Figure 4). The initial load of the nonirradiated green onions for IR and WW-IR treatments was 5.1 log CFU/g and 4.2 log CFU/g, respectively. Warm water (50 °C) treatment produced a 0.9 log CFU/g reduction in the number of aerobic microorganisms at the beginning of storage. However, this initial difference in TAC diminished and disappeared during subsequent storage. The use of a mild heat treatment to reduce the initial population of microorganisms has been recently reported. Delaquis and others (1999) showed that warm chlorinated water washes (47 °C, 3 min) initially reduced microbial populations by approximately 3 log CFU/g in shredded iceberg lettuce. Li and others (2001) also found that the populations of psychrotropic and mesophilic aerobic microorganisms, which naturally occur on iceberg lettuce, were decreased by a heat treatment at 50 °C for 1.5 min. The study of Cantwell and others (2001) with green onions (both green leaf and white stalk) found 1 to 2 logs reduction in TAC when the samples were treated with warm water at 52.5 °C for 4 min. Warm water treatment before cutting improved disinfection in comparison to treatment after cutting. Our results confirmed that warm water dip can generate an initial microbial reduction even at 50 °C for 20 s.

There was a significant difference in TAC between nonirradiated and irradiated samples at all doses ($P < 0.05$). Irradiation reduced initial populations by 3 to 3.5 logs. As a result, total aerobic microorganisms became undetectable (below 2.5 log CFU/g) until 4 d of storage for both treatments. During storage, TAC started increasing gradually on irradiated green onions at all doses. The samples irradiated at 1.5 kGy for both treatments, however, was undetectable (2 log CFU/g) throughout entire storage duration. The results of Fan and others (2003a) with fresh cilantro had results similar to ours. They reported that cilantro irradiated at 2 and 3 kGy had an over 2-log reduction in total plate count and a bacterial growth inhibition during 14 d of storage.

Conclusions

Irradiation at 0.5, 1.0, and 1.5 kGy effectively reduced initial microbial populations, and microbial growth was restricted upon subsequent storage. Irradiated samples exhibited a similar decay development and EL in the 1st 8 d of storage compared with the control. However, toward the end of the 14-d storage, irradiated samples maintained a relatively low decay percentage and EL. Sequential treatment of warm water dip and gamma irradiation caused additional loss of firmness at the end of storage than irradiation alone. Sensory evaluation also recorded significantly higher scores of overall visual quality and green color, and lower off-odor scores for irradiated samples. There was no significant difference in the quality parameters examined in this study between samples treated with and without warm water. Warm water wash did introduce a 0.9 log reduction, but this difference in initial TAC gradually diminished during storage.

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